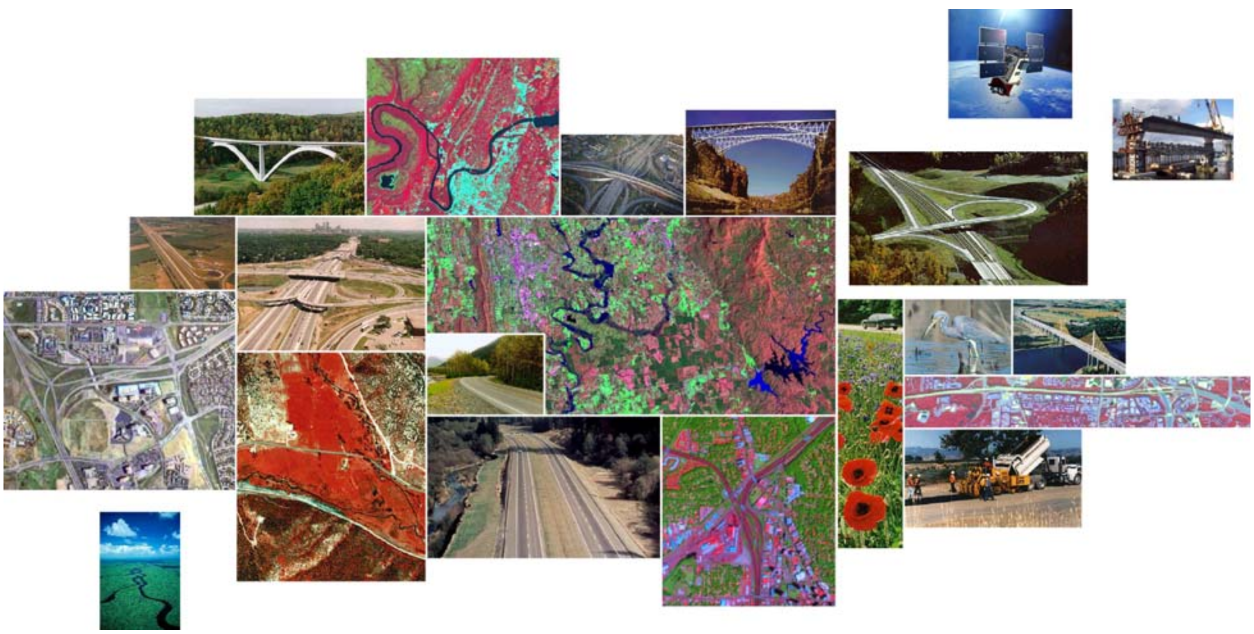
NCRST-E National Consortium for Remote Sensing in Transportation - Environmental Assessment

TECHNOLOGY GUIDE: NCRSTE_TG006

Hydrologic Impacts of Land Cover Change at Regional and Watershed Scales



December 2005

Prepared by
C. Laymon and J. Cruise
National Space Science and Technology Center
Global Hydrology and Climate Center
320 Sparkman Dr.
Huntsville, AL 35805

TABLE OF CONTENTS

PART I

Regional Scale Land Cover Classification and Change

1. INTRODUCTION

Planning and environmental assessment are transportation priority areas with high payoff potential for remote sensing. Planning is based on knowledge about the current state with some prediction as to how the state will change in the future. For long-range transportation planning by Federal, State, or metropolitan planning organizations, the information requirements may be less stringent as the focus is on characterizing general trends. Predicting the future is more precise if it is based on the historical trend projected through the present. The outcome of this process is to obtain a metric on trends and to steer thinking and planning activities internal to the organization. The accuracy of the prediction depends on the analysis method employed. Generally, however, data used for planning purposes is not required to meet precise accuracy standards.

Because the environmental assessment processes is complex and usually involves many players with different agendas, there is a pervasive perception that the environmental process results in extensive delays and additional costs in completing transportation projects. Part of the problem stems from the fact that the roles and responsibilities of federal, state, and local agencies are often in conflict. As a result of widespread concerns about delays, duplication of effort, and additional costs associated with NEPA and other environmental review processes, the US DOT, in response to Section 1309 of TEA-21, implemented a coordinated review process for construction projects that require environmental assessment. The goal of this review process is to establish performance measures and benchmarks to evaluate transportation and environmental decision-making for the purpose of reducing project delays.

Environmental streamlining brings together the timely delivery of transportation projects with the protection and enhancement of the environment. It is generally assumed that greater efficiency in acquiring and analyzing data used in EIS preparation, and better data standards, would reduce EIS preparation time and possibly result in less controversy over the report's findings. Environmental or development planning requires geospatial information about the distribution of landscape features. It is felt by many in the transportation industry that high-quality databases that are maintained with current or frequently updated geospatial information would streamline road development projects. Maps, and to some extent aerial photographs, are the traditional sources of this information. Remote sensing offers tremendous potential for planning purposes because it not only affords a picture of the current state, but unlike aerial photographs, multispectral data can be used to provide information classes, such as land cover and land use.

Remote sensing has numerous advantages over traditional data sets-it is unobtrusive; one can collect information simultaneously over a broad range of the electromagnetic spectrum; it is capable of making biophysical measurements; information can be acquired through clouds at long wavelengths; data can be collected in a very short timeframe with aircraft platforms and frequently with satellite platforms; data collection procedures are systematic thereby eliminating sampling bias introduced in some investigations; and analysis methods are relatively robust, objective, and repeatable. This is not to say that remotely sensed data necessarily replaces existing data sets, but in many cases it provides supplemental information that can lead to improved assessments.

Continuity in temporal classification of land cover and its extension to land use can play a significant role in preparation of a comprehensive development plan, implementation of "smart growth" initiatives, and are invaluable in the planning stage of road development projects. Most major metropolitan areas face the growing problems of urban sprawl; residential and commercial development is replacing undeveloped land at an unprecedented rate. Urbanization worldwide continues at a rapid rate and it is estimated by the United Nation's Population Fund (1999) that by the year 2025, 80% of the world's population will live in cities. Sprawl results in a loss of natural vegetation and open spaces and a general decline in the spatial extent and connectivity of wetlands, wildlife habitat, and agricultural lands. While land use changes are a consequence of national growth, regional assessments of historical and contemporary land use change are needed to anticipate the impacts associated with change and contribute to an understanding of productive environmental sustainability.

Land cover and land use changes as a result of sprawl can be substantial, but are difficult to grasp when they occur incrementally. Data from satellites has dramatically illustrated the rates at which these human-induced changes are occurring nationwide. Temporal mapping from satellite data has successfully demonstrated the utility of integrating existing historic maps with remotely sensed data and related geographic information to dynamically map urban land characteristics for large metropolitan areas. These regional databases provide a strong visual portrayal of recognized growth patterns, and dramatically convey how the progress of modern urbanization results in profound changes to the landscape. Temporal analysis of imagery data also allows calibration of transportation policy alternatives and identification of future trends using modeling.

2. OBJECTIVES

In this effort, we utilized archived remote sensing data for regional-scale assessment of historical changes in land cover that has occurred over a 91,000 km^2 area since 1980. More specifically, we develop multitemporal land use/land cover maps of the region and compare the observed trends in development and environmental change to changes in watershed hydrology. Whereas "development" is often quantified in terms of population or housing statistics in a geospatial context of counties, zip codes, or other "districts," remote sensing offers an alternative means of quantifying development in a pixel- or segment-based geospatial context. We analyze the long-term hydrologic trends of 18 watersheds of various sizes and comprised of different land cover types. Two watersheds, the Flint River, Alabama and Big Creek, Georgia are analyzed in more detail. Whereas these watersheds were principally rural in 1980, they have succumbed to urban sprawl over the past two decades, which has had a significant impact on the watershed's hydrology. We demonstrate some of the utility of remote sensing data in meeting requirements for environmental planning and assessment and gain valuable insight into where growth is occurring most rapidly and a synoptic view of consequent land cover change. Remote sensing offers a unique spatio-temporal view of sprawl unlike that afforded by socio-economic data. These changes are correlated with changes in hydrologic regime for the study area (Part II) that has a direct impact on water management issues.

3. STUDY AREA

The study area measures approximately 350 x 260 km comprising 60 Counties of the southern Appalachian region of northeastern Alabama, northwestern Georgia, and south-central Tennessee (Figure 1). This region includes the metropolitan regions of Atlanta, Georgia, Chattanooga, Tennessee, Birmingham, Alabama and Huntsville, Alabama.

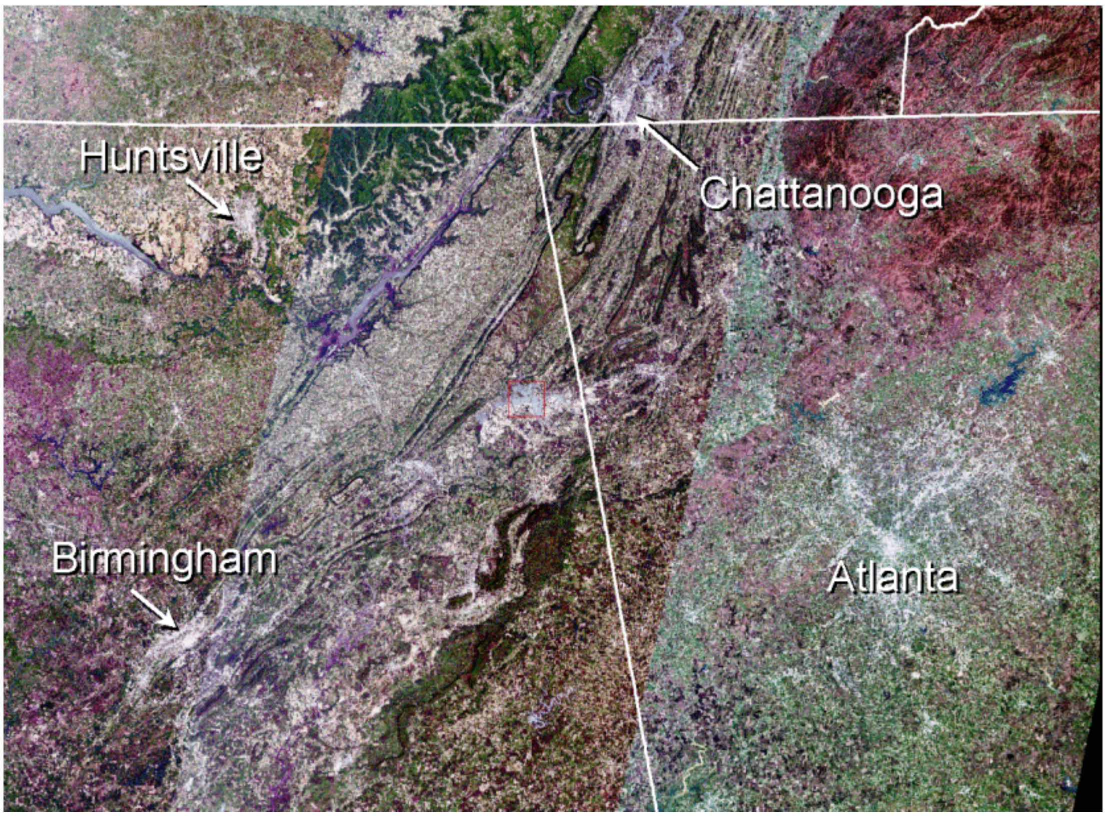


Figure 1: True color image composite of the regional study area comprised of portions of six Landsat Enhanced Thematic Mapper images. State boundaries (confluence of Alabama, Georgia, and Tennessee) are included and major cities are identified.

4. CLASSIFICATION METHODOLOGY

4.1. Data Acquisition

The study area spans most of the area covered by six Landsat images. These images were acquired from the Landsat archives at the EROS Data Center of the U.S. Geological Survey. Because of the time period of interest, images for each of the dates of interest, nominally 1980, 1990, and 2000, were acquired by different generations of Landsat sensors. The 1980 images were acquired by the Multispectral Scanner (MSS). The 1990 images were acquired by the

Thematic Mapper (TM) sensor and the 2000 images were acquired by the Enhanced Thematic Mapper Plus (ETM+) sensor (Table 1). An attempt was made to obtain "leaf-on" summertime images at decadal intervals, however, the availability of cloud-free images on certain paths required searching the archives forward or backwards one year.

Table 1: Specifications for images selected for the regional assessment project.

Target Date	Sensor	Path	Row	Acquisition Date	Resolution
1980	MSS	20	36, 37	8/7/1980	57 m
	MSS	21	36, 37	8/8/1980	57 m
	MSS	22	36, 37	6/13/1979	57 m
1990	TM	19	36, 37	9/28/1991	30 m
	TM	20	36, 37	9/16/1990	30 m
	TM	21	36, 37	9/26/1991	30 m
2000	ETM+	19	36, 37	4/5/2000	30 m
	ETM+	20	36, 37	5/14/2000	30 m
	ETM+	21	36, 37	4/19/2000	30 m

4.2. Georectification

The images were acquired in TIFF format with Space Oblique Mercator B projection with North American 1983 horizontal datum. All images were converted to the Universal Transverse Mercator projection using nearest neighbor resampling. The images from 1980 required additional manual processing to correctly rectify the images. Rectification accuracy was verified using Digital Line Graph data.

4.3. Atmospheric Correction

The radiance observed by a space-borne sensor is comprised of a component of energy reflected or emitted from Earth's surface as well as from scattering of energy in the atmosphere. The amount of scattering that occurs is a function of wavelength and must be assessed and explicitly removed from each image band. The atmospheric contribution to each image was removed using a modified form of the dark object subtraction technique.

4.4. Segmentation and Classification

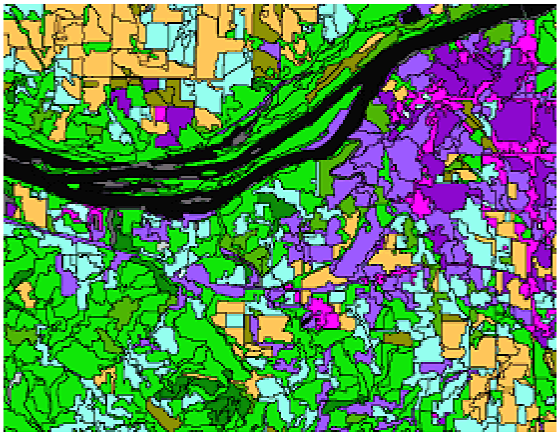
Atmospherically corrected image pairs from common paths were mosaicked and processed as a single image during segmentation and classification. Image transformation products were used to maximize the information content used in the segmentation and classification processes and to enhance the contrast among certain classes for improved classification success. For the 1990 and

2000 images, segmentation and classification was performed using all three bands from a decorrelation stretch transformation, three tassel cap transformation bands, and two ratio bands. Transformation products were not used for the 1980 images, because there are only four bands and there is little benefit from transformation products because of the reduced fidelity of the images. Images were segmented, that is, adjacent pixels with similar spectral characteristics were grouped into a segment or image object (Figure 2a and b). After supervised training by the image analyst, the segments are then classified (Figure 2c). Sixteen land cover and land use classes were defined for classification (Figure 3).

Figure 2a. True color image of a portion of the Western Corridor showing the Tennessee River at Tuscumbia, Alabama.

Figure 2b. Segmented image in which adjacent pixels have been grouped based on similar spectral characteristics. The yellow polygons delineate segments.

Figure 2c. Classified image in which each segment is assigned to a land cover type.



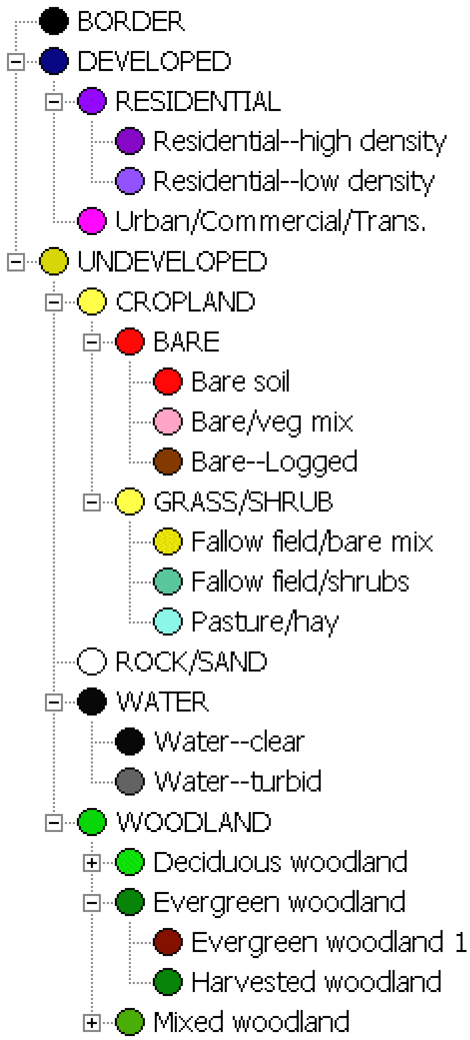


Figure 3. Classification system used in the regional assessment.

5. LAND COVER CLASSIFICATION RESULTS

A true color image mosaic of the study area provides a spectacular synoptic view of the region with its varied geology that controls topography, major and minor drainage ways, and the distribution of soils and vegetation types (Figure 4). Aside from the physiography, the seams between the images associated with the three different paths are noticeable. This is due to the differences in the image acquisition dates during the springtime when the landscape is transforming. The images in Paths 19 on the east side were acquired in early April 2000, just prior to emergence of the deciduous leaves. Thus, the urban and residential areas are highly visible. Cropland fields may still be covered in residue or winter weeds. The images in Paths 21 on the west side were acquired in mid April 2000 at the late stages of leaf out. Cropland fields have been cultivated in preparation for planting or have just been planted. The images in Path 20 in the middle of the image mosaic were acquired in mid May 2000 after crops have germinated.

These differences in transitional state greatly increase the difficulty of land cover classification. Nonetheless, such images provide valuable insight into the nature of the terrain and land cover and land use types that proposed highways might pass through. Mountains, floodplains and the number of water bodies that must be crossed or bypassed are readily identified on such images.

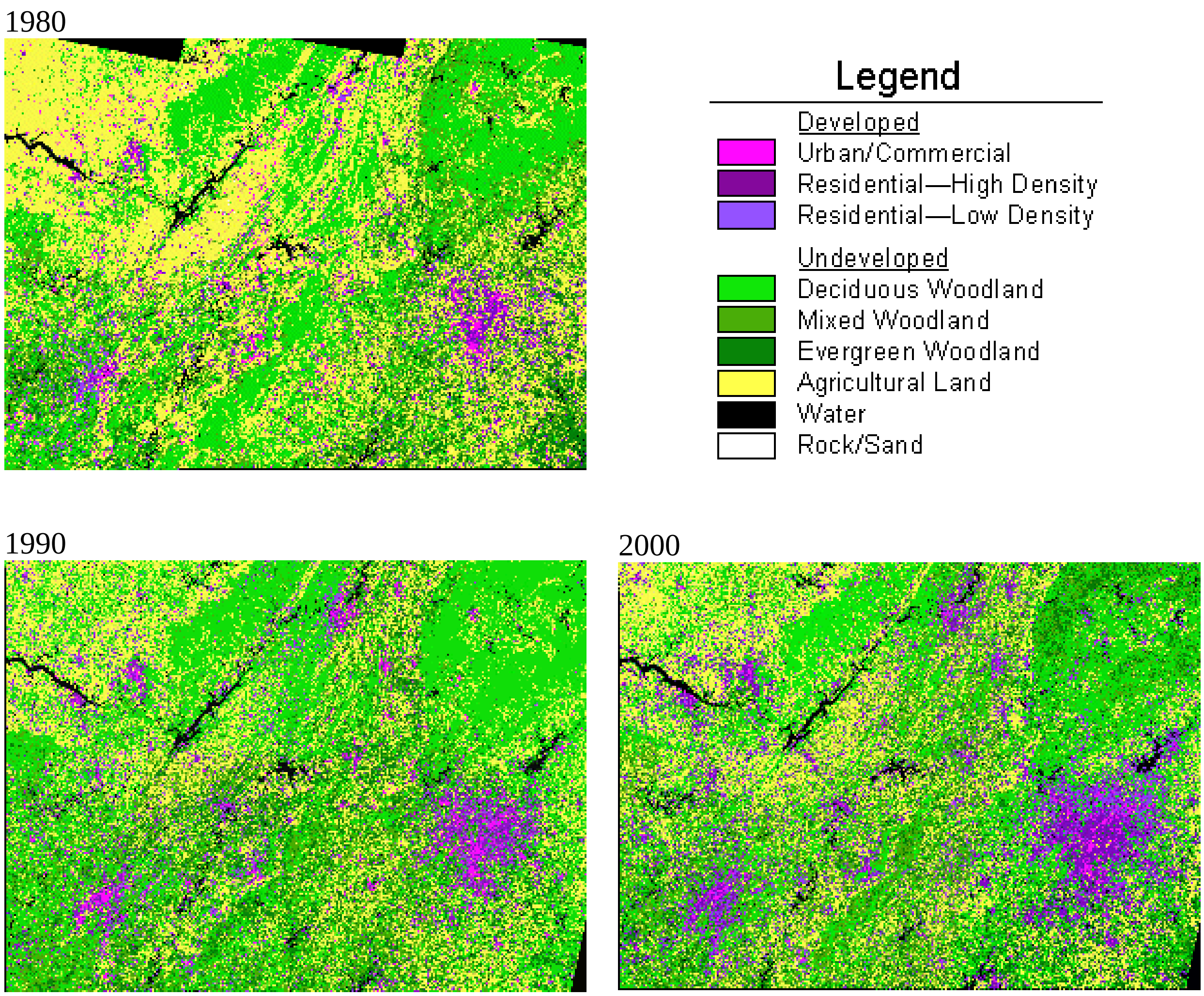


Figure 4. Remote sensing based land cover classification of the study area.

A study of historical trends in development of an area offers a new dimension to transportation planning. Figure 4 shows the remote sensing based land cover/land use classification for our regional-scale study area in 1980, 1990 and 2000. Table 2 provides the statistical results. From 1980 to 1990 the area of high density residential land remain relatively constant, however, between 1990 and 2000, there was a 72% increase in the amount of high density residential land. More significantly, between 1980 and 1990 the amount of low density residential land doubled, and between 1990 and 2000, the area of low density residential land doubled again! What appears to be a slight decrease in urban land cover is probably an artifact of the classification process and more than likely accounts for much of the apparent increase in high density residential land.

Table 2: Percent of total area assigned to different classes.

	1980 Pct. Area	1990 Pct. Area	2000 Pct. Area
Developed	8.3	10.1	14.9
Urban	2.6	2.1	1.5
Residential--high density	3.7	3.8	5.3
Residential--low density	2.0	4.2	8.2
Undeveloped	91.7	89.9	85.1
Cropland	40.5	26.7	27.3
Deciduous Woodland	28.9	37.4	28.4
Mixed Woodland	13.0	11.3	15.8
Evergreen Woodland	7.1	12.3	11.2
Water	2.2	2.2	2.4

The apparent large area of land classified as cropland in 1980 is largely an unfortunate artifact of the differences in resolution among the images. The images from 1980 have a resolution of 57 m, whereas the images from 1990 and 2000 have a resolution of 30 m. Most agricultural fields in this part of the U.S. are separated by narrow stands of trees (typically deciduous) along the boundaries of the fields. These stands are too narrow to be detected in the courser resolution data, thereby decreasing the area of land classified as Deciduous Woodland. Instead, cropland appears to be more contiguous in the 1980 classification than in the later dates.

If we collapse the classification down to just two classes, Developed and Undeveloped land, we get an unprecedented multidimensional view of development. Figure 5 shows the amount of developed land 1980, 1990, and 2000. Most of the growth is associated with the major metropolitan areas in the form of urban sprawl. However, significant growth in small satellite towns and cities is also readily apparent. From 1980 to 1990, the amount of developed land increased by about 2%; from 1990 to 2000, the amount of land that gave way to development increased by nearly 5%.

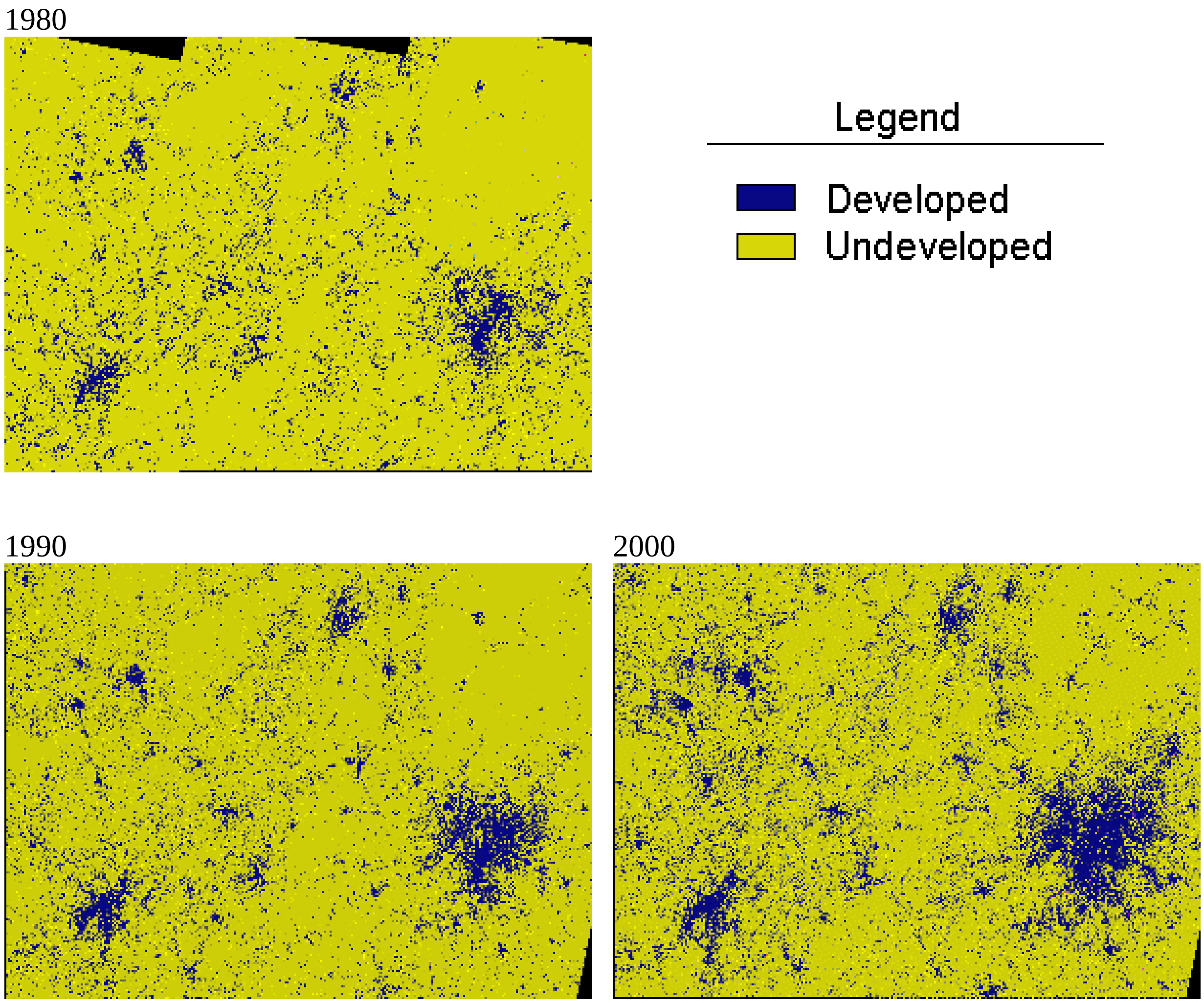


Figure 5. Remote sensing based classification of developed land area. NOTE: The image mosaic for the entire study area is a very large image. The 1980 mosaic measures 6127 x 4524 pixels, whereas the mosaic for 1990 and 2000 measures 12255 x 9048 pixels. These images had to be reduced in size significantly to make them portable. In so doing, much of the detail has been lost. Consequently, the images above should only be used for qualitative viewing purposes.

6. ANALYSIS OF HYDROLOGIC RESPONSE

The U.S. Geological Survey operates stream gages on rivers in each of these watersheds. Watersheds were chosen that were of an appropriate size such that changes in hydrologic response due to transportation- related land cover change would be evident. The criteria for selection included relatively long streamflow records, less than 900 square miles in area, wide distribution around the region, and representative of a variety of land use/land cover conditions from very rural forested and agricultural to predominantly urban watersheds. Nineteen watersheds that range in area from 72 to 885 sq. mi. met these criteria. Using the 1:250,000 scale DLG files available from the USGS Eros Data Center, the drainage areas of these watersheds were delineated in the ArcView GIS environment. These watersheds are shown in Figure 6.

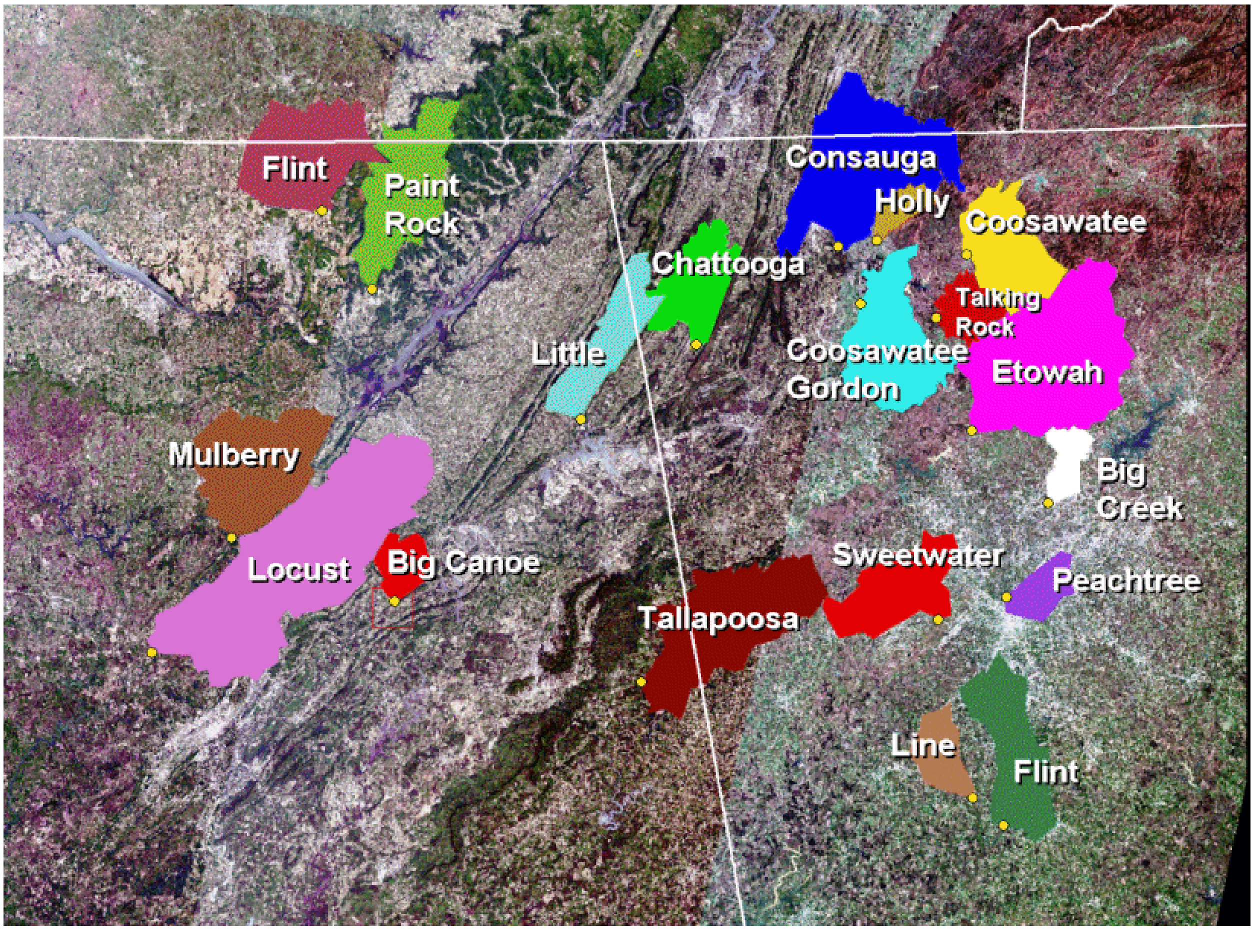


Figure 6. Location of the 19 watersheds used in this analysis. The yellow dots are at the locations of the stream gaging stations.

Figure 7 is a collection of plots showing annual peak streamflow in each of the watersheds from the beginning of the record or 1930 to 2002.

It was initially determined to characterize the hydrologic response within the region in terms of three variables. These variables were mean annual streamflow, frequency of inundation, and duration of inundation. These variables were selected due to their perceived relationship to ecosystem and environmental conditions. Mean water level, frequency of inundation above specified levels, and duration of these inundations could be related to various environmental concerns including wetlands identification, endangered species habitat and flood plain analysis. The streamflow records of the selected basins were examined for statistically significant time-dependent trends in all three of these variables.

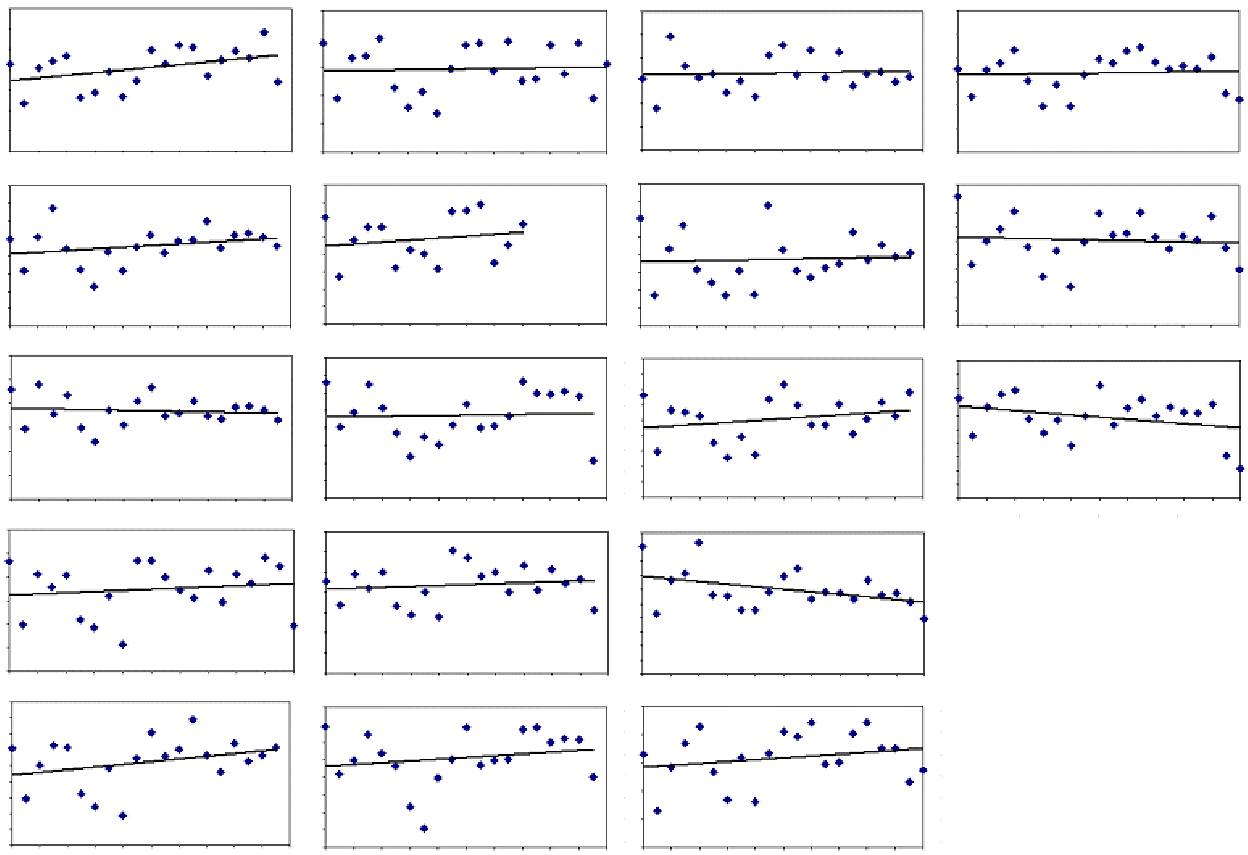


Figure 7. Rainfall-normalized mean annual streamflow from 1980 to 2000 for the 19 watersheds of the study area. The vertical scale for each plot is 0 to 0.8 in.

Mean monthly streamflow for each watershed streamgage was obtained from the permanent archives of the USGS. These data were used to determine mean annual flow for each year of record for each site. Mean monthly rainfall data was obtained for a large number of raingages throughout the study area. Mean annual streamflow (cfs) was converted to water depth and then normalize for total annual rainfall to remove possible climatological trends in rainfall that might bias streamflow records. Rainfall-normalized mean annual streamflow was plotted for the period 1980 to 2000. Trends in these time series are reflected in least squares regression (Figure 7). The slope of the observed trends is low; eight of the 19 are negative trends. Due to the short duration of the record (20 years) and high degree of temporal variability, none of the trends is statistically significant at the 0.05 level of significance. Nevertheless, these data suggest that for the period between 1980 and 2000, there may be a positive relationship between the slope of the trend in rainfall-normalized mean annual streamflow and the percentage change (increase) in developed land within each river basin (Table 3, Figure 8).

Table 3: Percent change in developed land in 19 watersheds and the associated trend in mean annual streamflow.

	Pct. Developed Land		Pct.	Regression
Watershed	1980	2000	Change	Slope
Big Creek	6.5	41.3	535	0.0343
Big Canoe	9.6	14.1	47	0.0451
Chattooga	4.8	10.3	115	-0.0222
Consauga	2.3	12.4	439	0.1211
Etowah	3.3	7.2	118	0.0360
Flint, AL	9.3	13.9	49	0.1087
Flint, GA	16.4	42.3	158	0.0109
Line	16.5	42.4	157	0.0260
Little	2.8	16.4	486	0.0176
Locust	12	16.4	37	0.0779
Mulberry	7.1	21.6	204	0.1248
Paint Rock	1.6	2.1	31	-0.1845
Peach Tree	29.5	91	208	0.0169
Sweetwater	35.1	48.9	39	0.0173
Tallaposa	7.1	10.8	52	-0.1630
Coosawatee	0.7	6.4	814	0.4326
Talking Rock	0.1	5.8	5700	-0.0108
Holly	0	7.8		0.0105

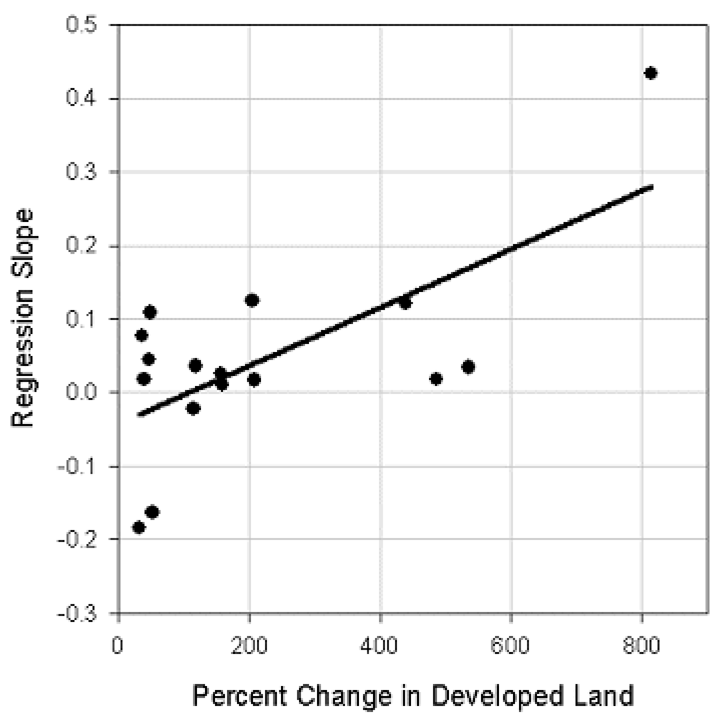


Figure 8. The relationship between the percent change in developed land versus trends in mean annual streamflow for the watersheds investigated.

The frequency of inundation above a given threshold value is merely the number of times each year that the streamflow exceeds the threshold limit. However, because this "frequency" is a discrete random variable (a tally of occurrence), its sampling distribution is unknown and therefore cannot be examined directly for statistical significance. In order to analyze these data by Poisson regression, the data must be transformed using a technique described by Keim and Cruise (1997). This technique is based on the assumption that a Poisson counting process can represent the frequency of occurrence of events above a certain threshold level, then the time intervals between recurrences of the process are exponentially distributed. The data series (intervals between events) can then be summed in groups of two or four (depending on the length of the record and the desired power of the test) in order to transform the data to log-normally distributed random variables. Next, the data are further transformed to a normal distribution by merely taking the logarithm of each summed group. This data series is then regressed against the cumulative midpoints of the summation of the group times in days and the regression holds exactly.

The first step in the application of Poisson regression is to find the threshold limit at which the counts of occurrences are Poisson distributed. Figure 9 shows the peak annual streamflow for each watershed. A test first devised by Cunnane (1973) and later expanded by Cruise and Arora (1990) can be used to make this determination. The test relies on the fact that the mean and variance of the Poisson distribution are equal. Thus, the ratio, R = Var(n)/E(n) (where n is the number of events per year) should approach unity as the threshold level is increased if the process is indeed Poisson admissible (Cruise and Arora, 1990). The R values are tested using the test statistic R(N-1) which is known to be c^2 distributed (Cunnane, 1973) and where N = total number of years of record. Thus, the critical R value would be given by Rc = c^2 (N-1), a/N-1. Keim and Cruise (1998) recommend a significance level of 0.1 for this one-tailed test.

The daily streamflow data were obtained for each of the 10 watersheds for which annual trends were identified and the test described above was applied to each series. In all ten cases, a threshold level for Poisson admissibility was successfully identified. Once the lowest Poisson admissible threshold is identified, the series will theoretically remain Poisson distributed for all thresholds above this value. The next step is to determine the number of days between recurrences of streamflow events above the threshold level. This was accomplished for each data series and then the steps described above were completed to determine if significant trends in frequency of inundation above the thresholds were evident.

In the duration analysis, the same threshold values were used as in the frequency analysis for consistency purposes. The analysis of durations is made more easily since the annual duration of flooding events has traditionally been assumed to be a log-normally distributed variable due to the fact that the series arises through a summation process. Thus, the procedure merely consisted of determining the number of days each year that each stream remained above the determined threshold and taking the logarithms of these values. The logarithms were then regressed against cumulative time in days to determine if significant trends exist.

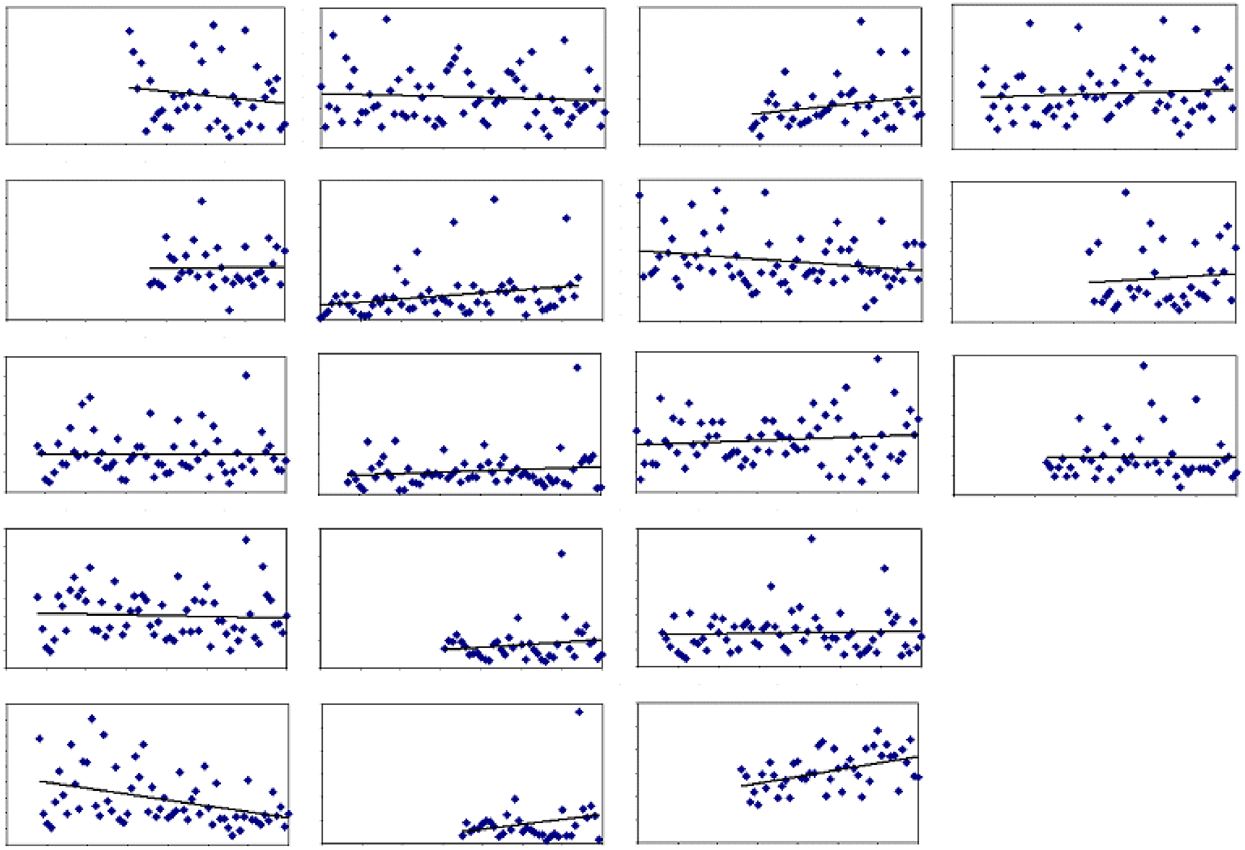


Figure 9. Annual peak streamflow in the 19 watersheds from 1930 to 2002. The vertical scale for each plot varies to match the dynamic range of data as streamflow varies for each watershed.

PART II

Watershed Scale Land Cover Classification and Change: Flint River Watershed

7. FLINT RIVER WATERSHED

Huntsville and Madison County, Alabama (Figure 10) have continued to grow steadily since the 1950's. This growth has had a marked effect on the remaining green space within the County. The Land Trust of Huntsville and North Alabama, which is dedicated to preserving lands for public use to enhance recreation, education, conservation and prosperity in the North Alabama region, recognizes that some of this land is a valuable resource and worth protecting from urban sprawl. The spatio-temporal information afforded by satellite data can be used to illustrate where changes have occurred and to quantify the rate of urban sprawl and concomitant loss of green space. These data provide the basis for understanding urban growth changes within an historical perspective.

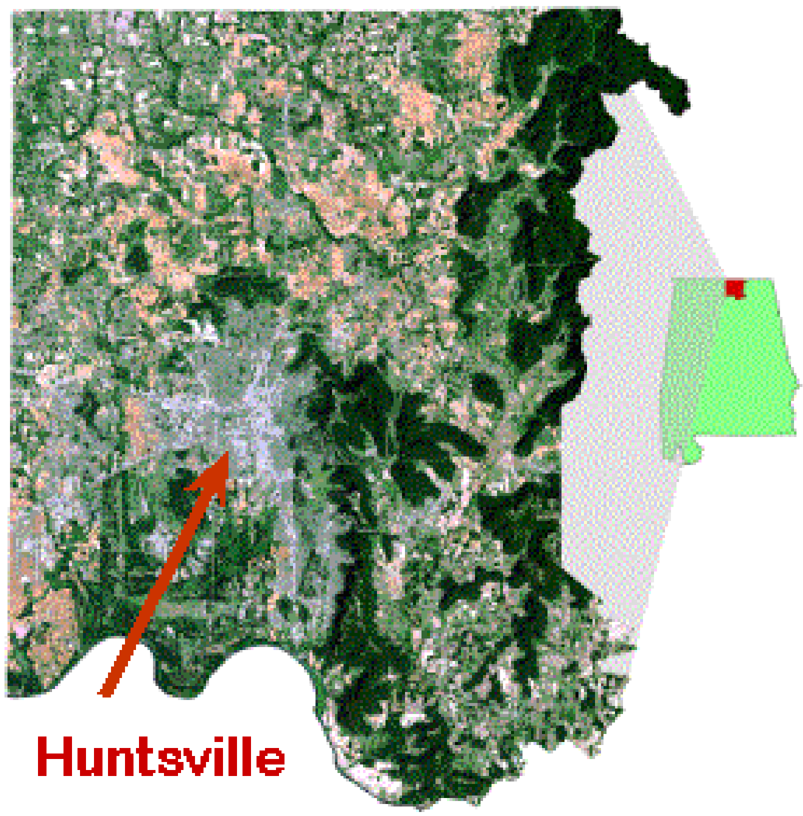


Figure. 10. Pseudo true-color satellite image of Madison County, Alabama.

The Flint River watershed with and area of 568 square miles is a tributary to the Tennessee River. Much of the watershed (342 sq. mi.) is contained in Madison County, Alabama (Figure 11). The land within this watershed is predominantly agricultural and has experienced significant recent residential growth from the City of Huntsville. The U.S. Geological Survey National Water-Quality Assessment Program is currently investigating water quality in the lower Tennessee River basin with several monitoring activities targeted in the Flint River Basin (Hoos et al., 2002).

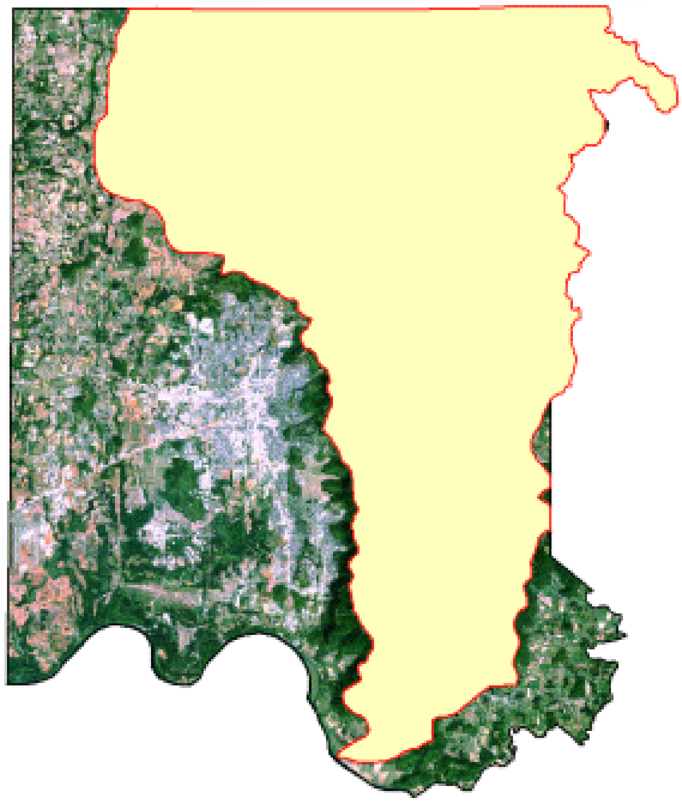


Figure 11. Map showing the location of Flint River Basin in Madison County, Alabama. A very small portion extends into Tennessee to the north.

The land in Madison County, Alabama has been developed at an observed annual rate of 1% per year for the last 16 years. In 2000, developed land comprised 30% of the county. At this rate, by 2020 nearly 50% of the county will be developed based on estimated growth from the satellite images.

Urbanization worldwide continues at a rapid rate and it is estimated by the United Nation's Population Fund (1999) that by the year 2025, 80% of the world's population will live in cities. Most major metropolitan areas face the growing problems of urban sprawl; residential and commercial development is replacing undeveloped land at an unprecedented rate. Sprawl results in a loss of natural vegetation and open spaces and a general decline in the spatial extent and connectivity of wetlands, wildlife habitat, and agricultural lands. While land use changes are a consequence of national growth, regional assessments of historical and contemporary land use change are needed to anticipate the impacts associated with change and contribute to an understanding of productive environmental sustainability.

These land cover and land use changes can be substantial, but are difficult to grasp when they occur incrementally. Recently, data from satellites has dramatically illustrated the rates at which these human-induced changes are occurring nationwide. Temporal mapping from satellite data has successfully demonstrated the utility of integrating existing historic maps with remotely sensed data and related geographic information to dynamically map urban land characteristics for large metropolitan areas. These regional databases provide a strong visual portrayal of recognized growth patterns, and dramatically convey how the progress of modern urbanization results in profound changes to the landscape.

8. LAND COVER CLASSIFICATION

The land cover analysis was based on data from the Landsat series of satellites, which provide one of the most extensive and continuous terrestrial imagery archives. Since the beginning of the Landsat program in 1972, data have been acquired from three different generations of sensors, the Multispectral Scanner, Thematic Mapper and Enhanced Thematic Mapper Plus data. Landsat imagery of the globe is subset and marketed as a patchwork of individual scenes identified by a row and path designation. Images from Landsat's Thematic Mapper instrument were acquired for 1984 and 1990 and from Landsat's Enhanced Thematic Mapper instrument for 2000. Land surface features were assigned to one of 13 classes, such as commercial, residential, deciduous woodland, cropland, etc. (Figure 12). The resulting images can then be processed mathematically to compute land area that has changed from one class to another.

To assess the change in land use over the 16-year period from 1984 to 2000, land cover/land use classes were aggregated into "Developed" and "Undeveloped" superclasses. The difference between these maps reflects changes in the distribution of Developed and Undeveloped land that has occurred during the intervening periods.

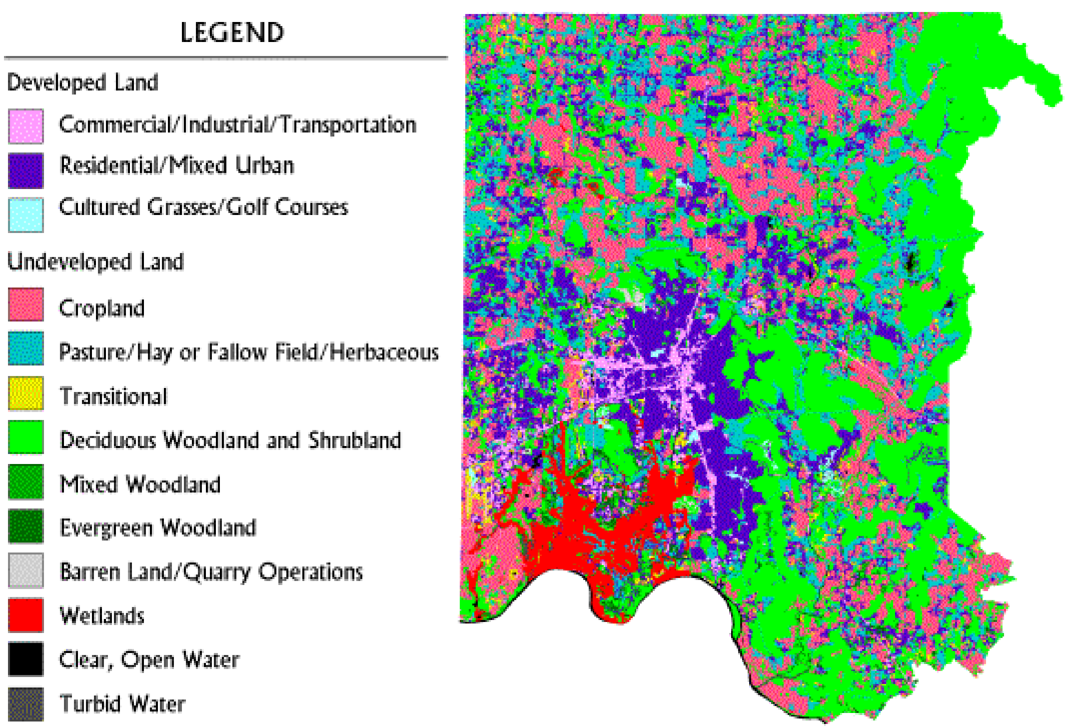


Figure 12. Land cover/land use classification of Madison County, Alabama for May 2000

Between 1984 and 2000, Madison County experienced strong growth resulting in an increase in developed land area at an average rate of 1% per year (Figure 13 and 14). In all, 16.1% of the land in Madison County changed from Undeveloped to Developed. Development occurred nearly three times as fast between 1984 and 1990 than it did between 1990 and 2000. In 1984, 13.4% of the total land area of Madison County was developed. One area experienced nearly a 10-fold increase in developed land area. The statistics for area of developed land in Madison County are consistent with population changes that have occurred in Madison County.

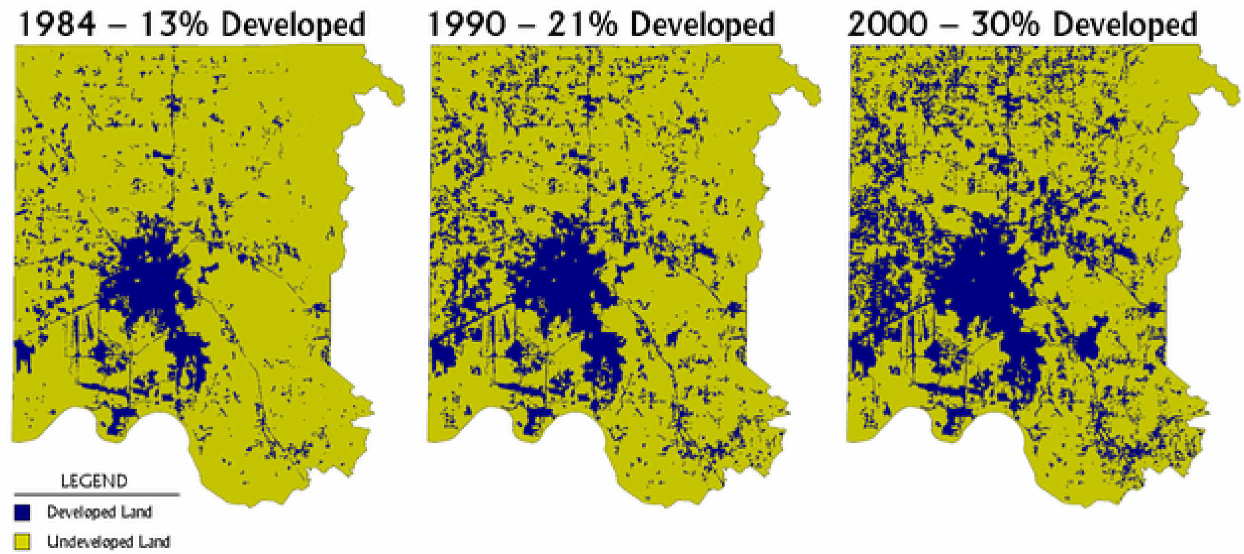


Figure 13. Maps showing the distribution of Developed and Undeveloped land in Madison County in 1984, 1990, and 2000.

Once maps of land cover/use change are developed, these data can be integrated in a GIS environment with other types of planimetric data to compute change on other aerial bases. For this project, change in developed land area was determined for individual cities and townships, real estate zones, and particular watersheds (Figure 15, 16, and 17). These results lead to a more comprehensive interpretation of urbanization and may point to factors that have stimulated development in different areas or may identify potential consequences.

In 1990, 21.4% of the County was developed reflecting a 59.3% increase in the amount of Developed land. In 2000, 29.5% of the County was developed. Observations of developed land area for 1984, 1990, and 2000 were projected into the future and suggest that 38% to 50% of the land in Madison County may be developed by 2020. These data are valuable to development and planning agencies and in educating and engaging the public in the need to preserve and enhance our community's natural resources before the losses are irretrievable.

Table 4 shows the area of Developed and Undeveloped Land in the Flint River Watershed in 1984, 1990 and 2000 as determined by classification of satellite remote sensing imagery. These data are shown graphically in Figure 18. In 1984, 5.5% of the basin in Madison County was developed. By 1990, the area of Developed Land had increased by 121% to 12.1% of the area of the basin in Madison County. By 2000, the area of Developed Land had increased by an additional 67% to 20.2%. Over the 16-year period, the area of Developed Land increased by an average of almost 1% per year.

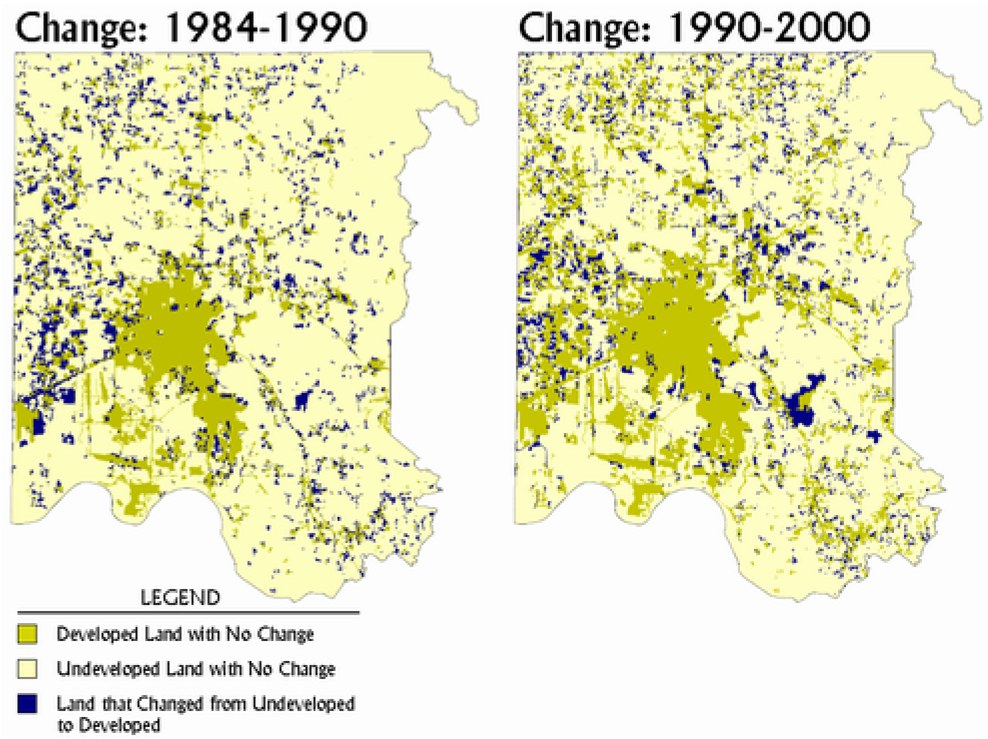


Figure 14. Map showing the distribution of Developed and Undeveloped land in Madison County that experienced no change in land use from 1984 to 1990 or from 1990 to 2000, and land that changed from Undeveloped to Developed.

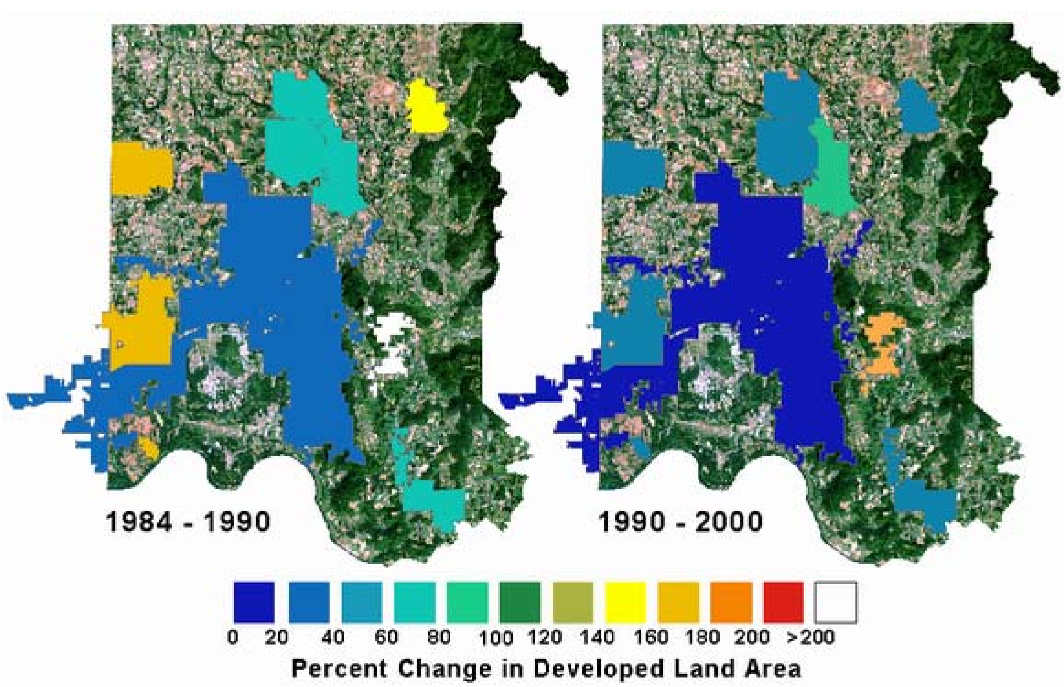


Figure 15. Maps showing the percent change in Developed land area for cities and townships in Madison County between 1984 to 1990 and 1990 to 2000.

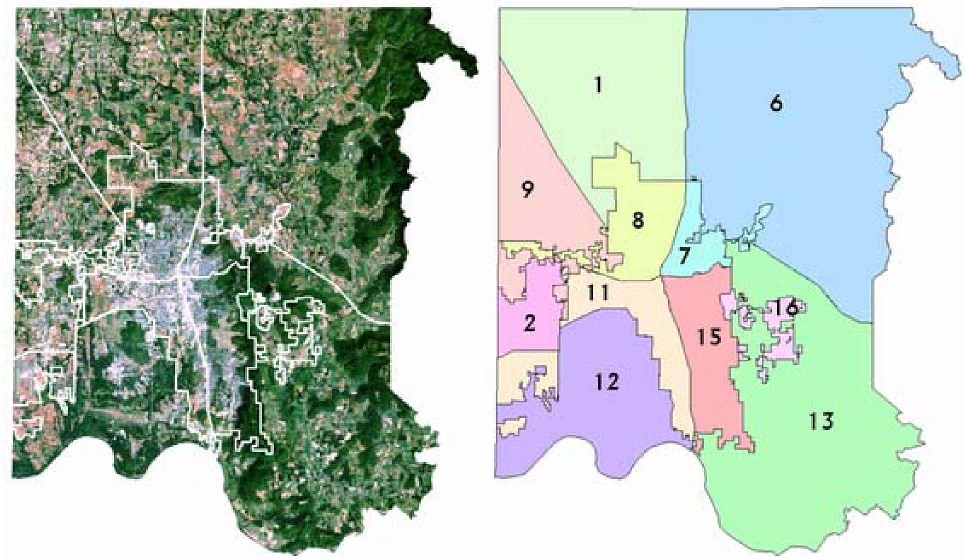


Figure 16. Map showing the location of real estate zones in Madison County for which land use change assessment was made.

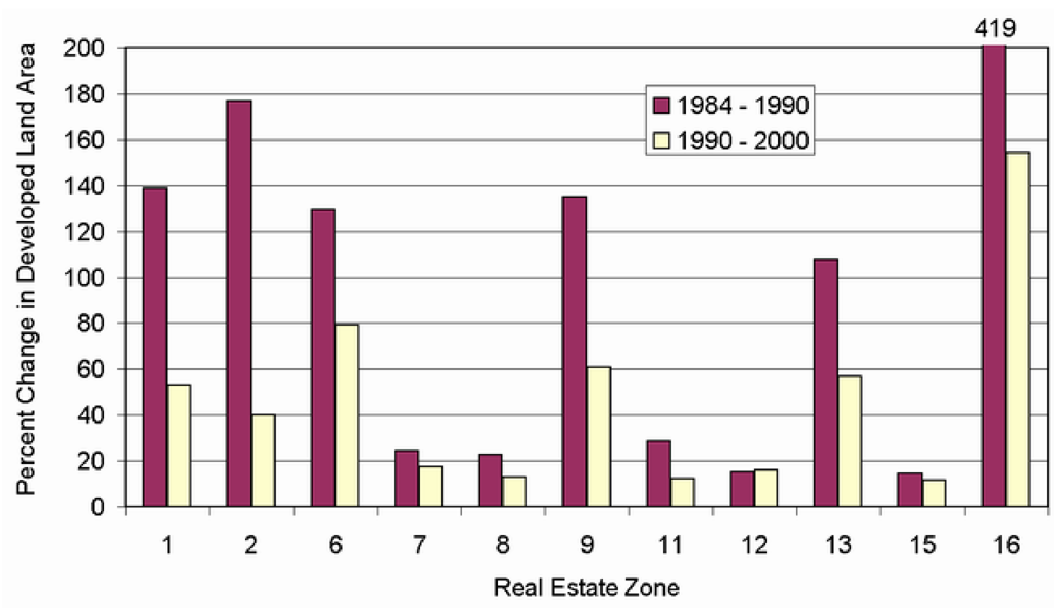


Figure 17. Chart showing the percent change in Developed land area between 1984 and 1990 and between 1990 and 2000 for real estate zones of Madison County.

9. HYDROLOGIC RESPONSE

From 1980 to 1994, rainfall-normalized mean annual streamflow increased by 17% (Figure 19). (In 1994, the gaging station was moved down river several miles. The new streamgage did not begin acquiring data until 1996, however, these data are not directly comparable). If the trend in streamflow was projected to the present year, we could estimate that streamflow in the Flint River Basin to be 29% greater than it was in 1984. The reason for the increase in streamflow is not known with certainty, but these data suggest that it is related to the increase in the percentage of Developed Land.

Table 4: Area of Developed and Undeveloped land in Flint River watershed and associated statistics.

Year	Developed (Hectares)	Undeveloped (Hectares)	Area Total (Hectares)	% Dev Land	% Chg	% Chg Per Year	Total Chg	Total Chg Per Year
1984	6256	108170	114427	5.5				
1990	13826	100601	114427	12.1	121.0	20.2		
2000	23102	91325	114427	20.2	67.1	6.7	14.7	0.9

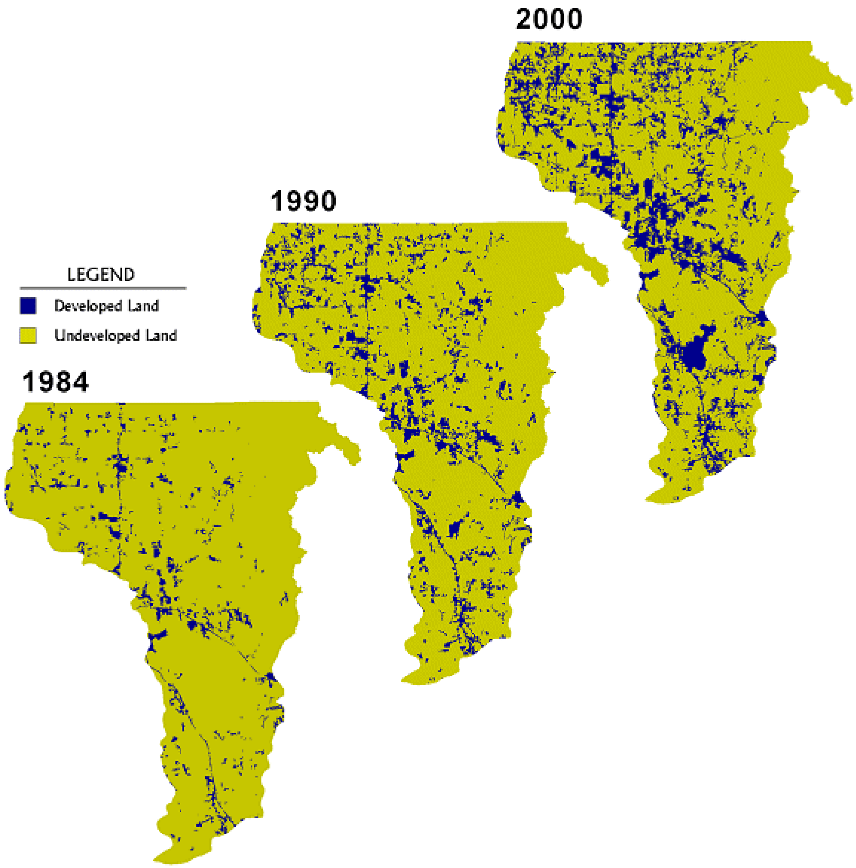


Figure 18. Maps of the portion of Flint River Basin in Madison County, Alabama showing the distribution of Developed Land in 1984, 1990, and 2000.

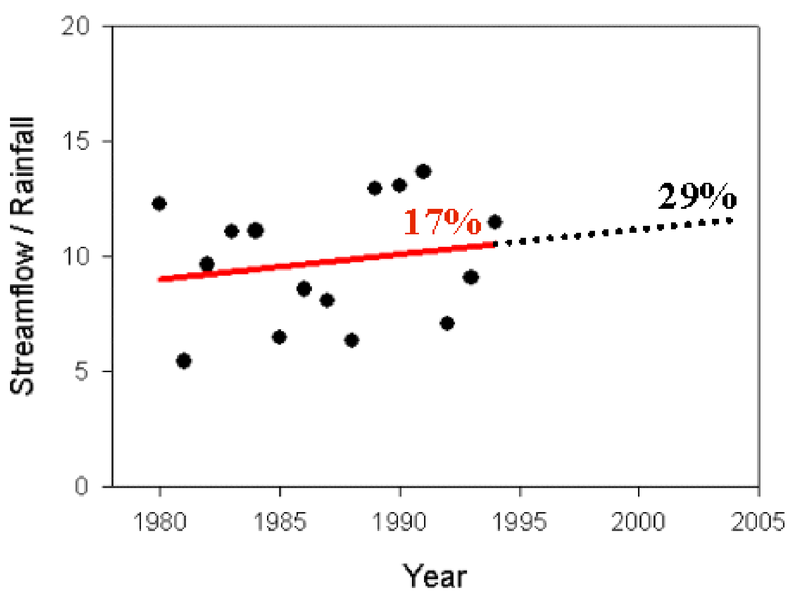


Figure 19. Graph of rainfall-normalized mean annual streamflow in Flint River Basin from 1980 to 1994 showing an increase of 17% over this period and a projection to 2004 suggesting a total increase of 29% over 1980 values.

PART III

Watershed Scale Land Cover Classification and Change:
Big Creek Watershed

10. BIG CREEK WATERSHED

The Big Creek watershed is a small basin on the northern fringe of Atlanta, Georgia's vast urban sprawl (Figure 20). The area of the basin is approximately 72 square miles upstream from USGS Gage # 02335700 (Big Creek near Alphareta, GA) and is contained in three counties: Fulton, Forsyth and Cherokee. From 1980 to 2000, the population of the basin increased by 200% and the number of new businesses increased 15-fold. Increases in developed land of this magnitude are associated with concomitant increases in impervious surfaces, which have a significant effect on the hydrologic regime. Whereas "development" is often quantified in terms of population or housing statistics in a geospatial context of counties, zip codes, or other "districts," remote sensing offers an alternative means of quantifying development in a pixel- or segment-based geospatial context. Because of the magnitude of changes within Big Creek, it was selected for study using remote sensing imagery to classify land use and land cover of Big Creek. Changes in the percentage of developed land within the watershed are correlated to changes in streamflow at decadal intervals.

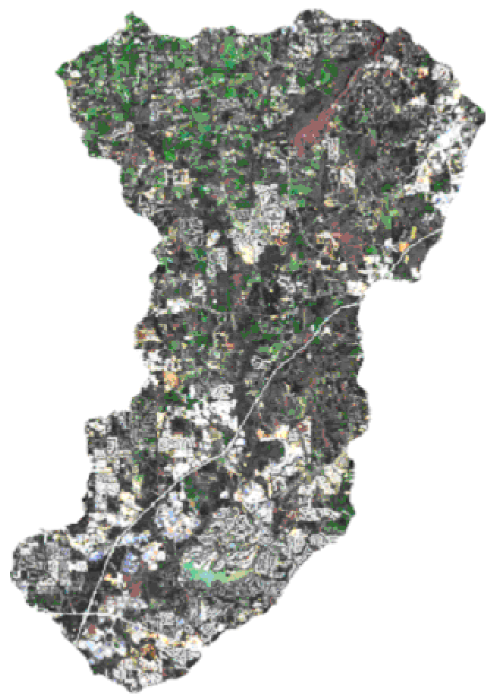


Figure 20. Map showing the location of Big Creek with respect to Atlanta, GA and a "true-color" image of Big Creek watershed as viewed from space in the year 2000. Click on image for a larger version.

11. LAND COVER CLASSIFICATION

11.1. Data Acquisition

Three Landsat images were acquired for the purpose of classifying land cover in the Big Creek watershed. The watershed is fairly small and is contained well within a single image. Only summertime images were acquired during the time of year when the vegetation is fully leafed out. The images acquired are identified in Table 5. None of the images collected in 1990 were cloud-free so an image from 1991 was acquired instead. Each of the images were obtained from a different generation of sensor. The MSS sensor has the lowest spatial and radiometric resolution and thus limits the overall number of classes that can be satisfactorily achieved.

Table 5: Specifications for images acquired for the Big Creek classification.

Target Year	Sensor	Path	Row	Acquisition Date	Resolution
1980	MSS	20	36	08/07/1980	57 m
1990	TM	19	36	09/28/1991	30 m
2000	ETM+	19	36	04/05/2000	30 m

11.2. Georectification

The images were acquired in TIFF format with Space Oblique Mercator B projection with North American 1983 horizontal datum. All images were converted to the Universal Transverse Mercator projection using nearest neighbor resampling. The image from 1980 required additional manual processing to correctly rectify the images. Rectification accuracy was verified using Digital Line Graph data.

11.3. Atmospheric Correction

The radiance observed by a space-borne sensor is comprised of a component of energy reflected or emitted from Earth's surface as well as from scattering of energy in the atmosphere. The amount of scattering that occurs is a function of wavelength and must be assessed and explicitly removed from each image band. The atmospheric contribution to each image was removed using a modified form of the dark object subtraction technique.

11.4. Segmentation and Classification

In the preliminary classification, the decorrelation stretch images from both March and September 2001 and the tassel cap transformation image from March 2001 were used in the classification. Use of transformation products is sometimes used to reduce the information content of images to a smaller number of bands. In this case, the benefit was minimal so that the final classification was based on the six bands from the March 2001 image and bands 2, 4, and 5 from the September image (Figure 2a).

First, the image is segmented. That is, adjacent pixels with similar spectral characteristics are grouped into a segment or image object (Figure 2b). After training by the image analyst, the segments are then clustered into classes (Figure 2c). Thirteen land cover and land use classes were defined for the classification (Figure 21).

11.5. Classification Results

Classification results for Big Creek watershed are shown in Figure 22. In Figure 23, the classification is collapsed into two principle classes, Developed and Undeveloped, to highlight growth in the watershed as a result of urban sprawl on the northern fringes of Atlanta. Woodland, which comprises about 30% of the watershed, remained fairly constant between 1980 and 2000. Fields, however, either pasture and/or fallow cropland, exhibit the greatest change from about 17.6% in 1980 to 9.4% in 1990 to 3.7% in 2000. Overall, Developed Land comprises about 11.7% of the watershed in 1980 and 17.0% in 1990, but increased to 31.6% 2000. These figures correspond to a 45% increase in Developed Land during the first decade and a 86% increase during the second decade.

Figure 21. Classification system used in the classification of Big Creek watershed.

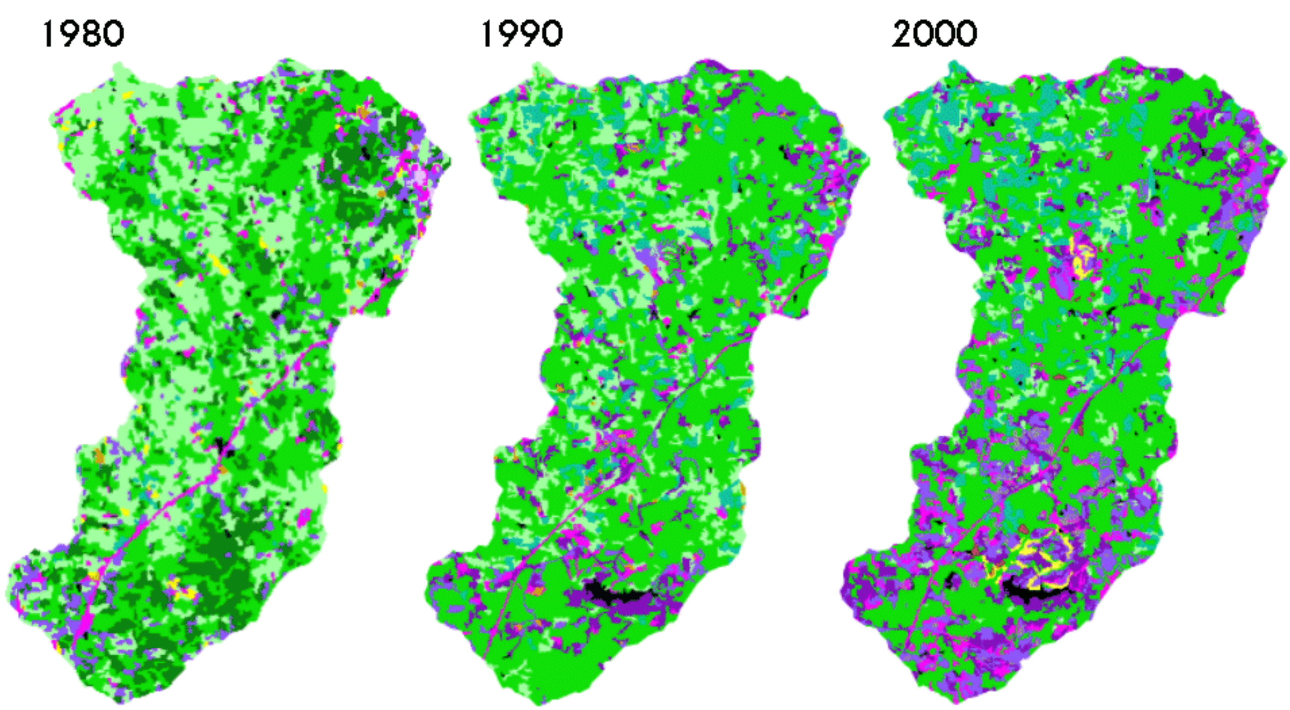


Figure 22. Land cover classification for the Big Creek watershed in 1980, 1990, and 2000.

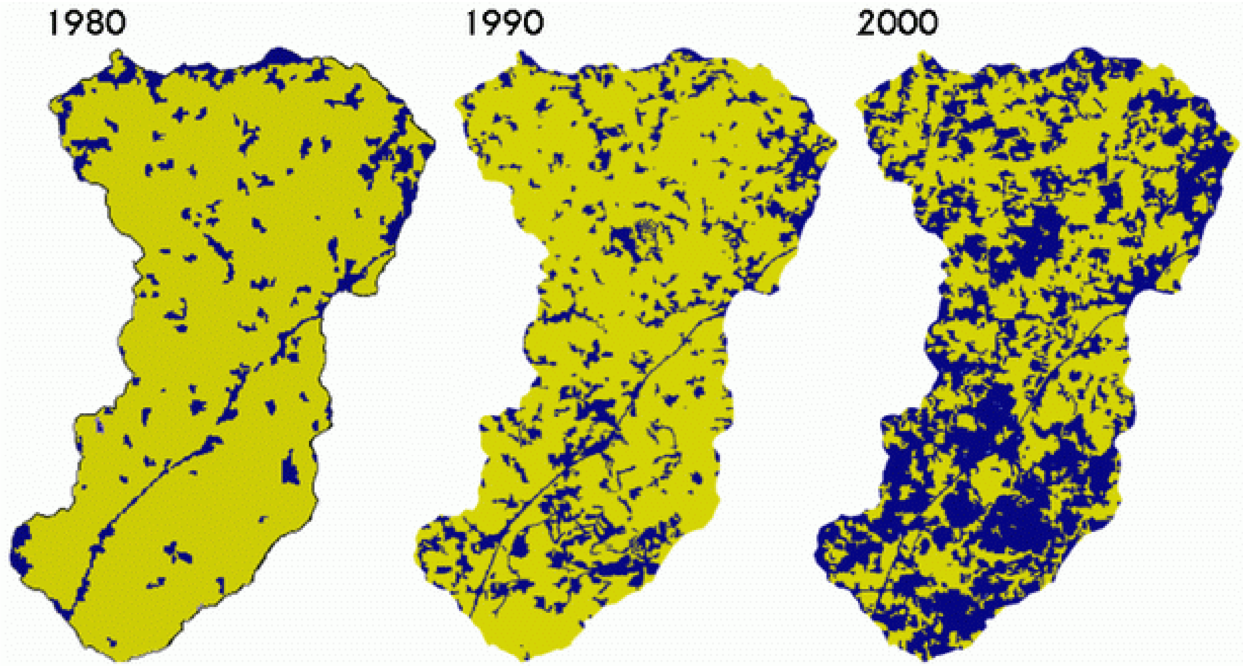


Figure 23. Maps of Big Creek Basin, Georgia showing the distribution of Developed Land in 1980, 1990, and 2000 as determined from classification of satellite remote sensing imagery.

12. POPULATION DEMOGRAPHICS

The annual population within Big Creek watershed was obtained from US Census data. The basin's population increased by 104% from 1980 to 1990 and by an additional 105% from 1990 to 1998 (Figure 24). During the period between 1980 and 1998, the number of new business starts increased 15-fold (Figure 24). The estimated 1998 population distribution based on Tiger census blocks is shown in Figure 25.

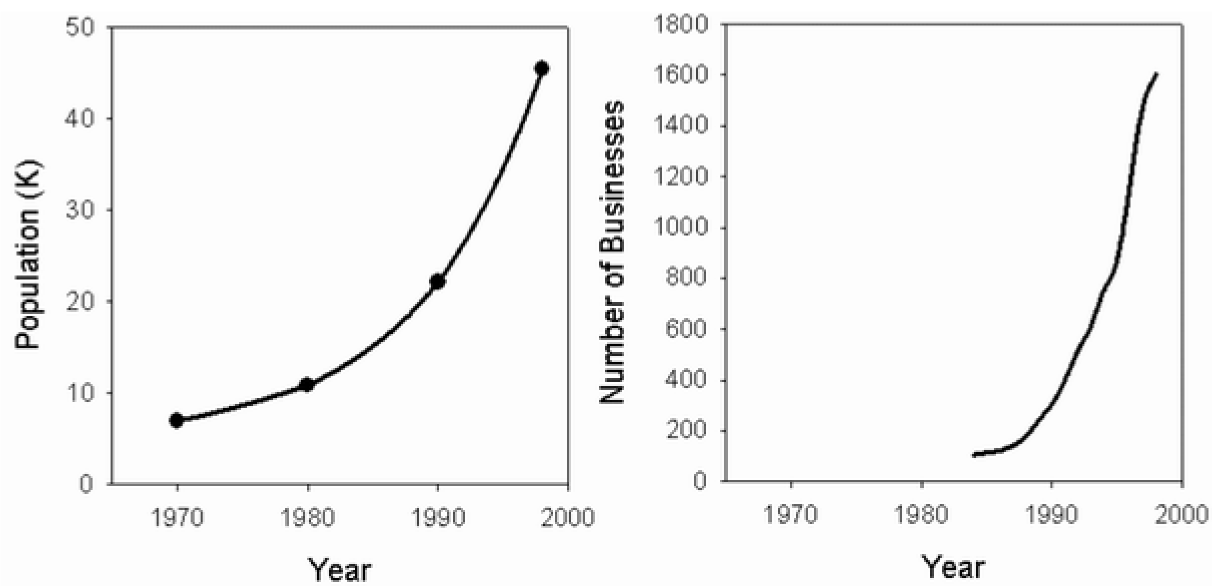


Figure 24. Graph of population growth in Big Creek watershed from 1970 to 1998 (left) and number of new business starts from 1984 to 1998 (right).

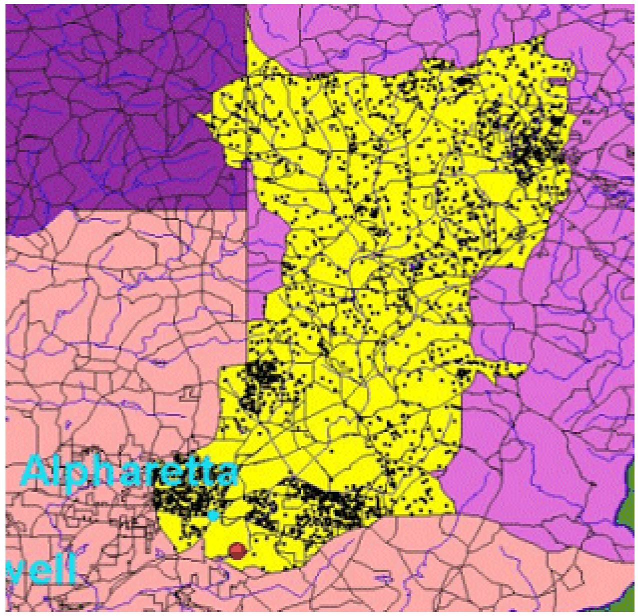


Figure 25. 1998 population distribution in Big Creek watershed estimated for Tiger census tracts.

13. HYDROLOGIC RESPONSE

Changes in the percentage of developed land within the watershed are correlated to changes in streamflow at decadal intervals. In 1980, 12% of the area of the watershed was Developed Land. In 1990, Developed Land area had increased by about 40% to 17% of the area of the basin. From 1990 to 2000, the area of Developed Land had nearly doubled to 32% or nearly one-third of the area of the basin. Figure 26 shows rainfall-normalized mean annual streamflow for Big Creek from 1960 to 2000. From 1960 to 1985, streamflow was fairly consistent with a slight positive trend. From 1985 to 2000, however, mean annual streamflow was highly variable. Although there is a significant positive trend during this latter period, there is not a significant increase in streamflow because of a general decrease in streamflow during the latter half of the 1980's. Causality cannot be determined with any certainty, but clearly the increase in variability since about 1985 is highly correlation with an increase in Developed Land area.

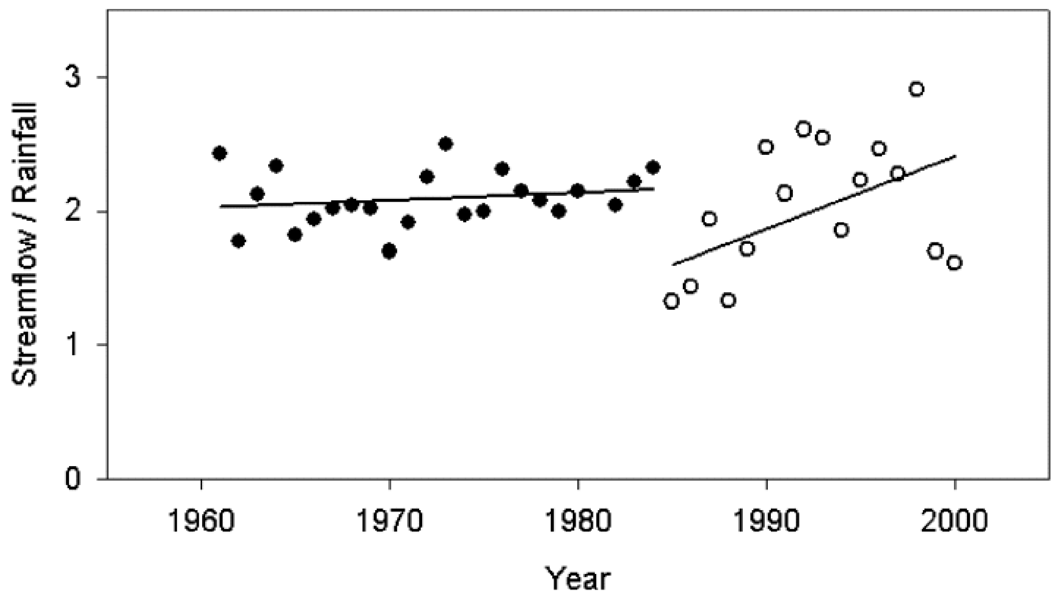


Figure 26. Graph of rainfall-normalized mean annual streamflow in Big Creek Basin from 1960 to 2000. The period from 1985 to 2000 is shown with different symbology, as the streamflow behavior is markedly distinct from the preceding period.

REFERENCES

Cruise, J.F. and Arora, K., 1990. A hydroclimatic application strategy for the Poisson partial duration model, Wat. Res. Bull., 26(3): 431-442.

Cunnane, C., 1973. A note on the Poisson assumption in partial duration series models, Water Resources Research, 15(2): 489-494.

Hoos, A.B., Garrett, J.W., an Knight, R.R., 2002. Water Quality of the Flint River Basin, Alabama and Tennessee, 1999-2000., Water-Resources Investigations Report 01-4185, U.S. Geological Survey, Nashville, TN, 37p.

Keim, B.D. and Cruise, J.F., 1998. A technique to measure trends in the frequency of discrete random events, Journal of Climate, 11(5): 848-855.